Chapter 1

Power Supply

Power Supply

Fritz Richner

1. INTRODUCTION

A cement plant is considered a big consumer of electrical energy. The energy consumption is comparable to the one of a small town, e.g. 15'000 habitants of a town require approx. 20 MW of electrical power - the equivalent of a cement plant with a production capacity of 2000 tons/day.

The cement production process is a continuous process and depends on a very reliable power supply system and distribution network. Any interruption in the power supply means a loss in production and causes a lot of trouble.

The reliability of a power supply depends on the:

- design of the supplying network
- atmospheric conditions
- strength of the supply

$P_{inst} \simeq 10\,kW \times$ ... tonnes/jour / 100 kWh/t.

In the following a short description of the commonly used generation and systems is given.

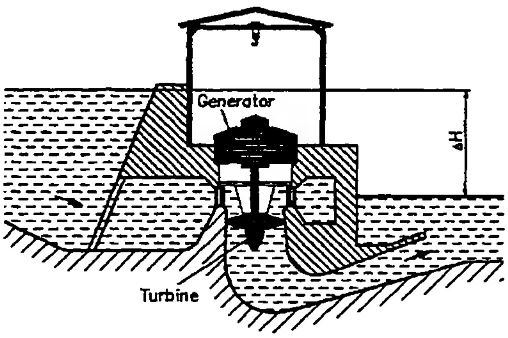
2. POWER GENERATION

The geographical location, the climate and the level of technical and economical development of a country are decisive factors for the selection on the type of power generation systems. A mix of several systems may be of advantage in order to cope with the fluctuating power requirements of industries and public consumers during the charging phases of the day or the year.

The following are the most commonly used power generating systems and their main characteristics.

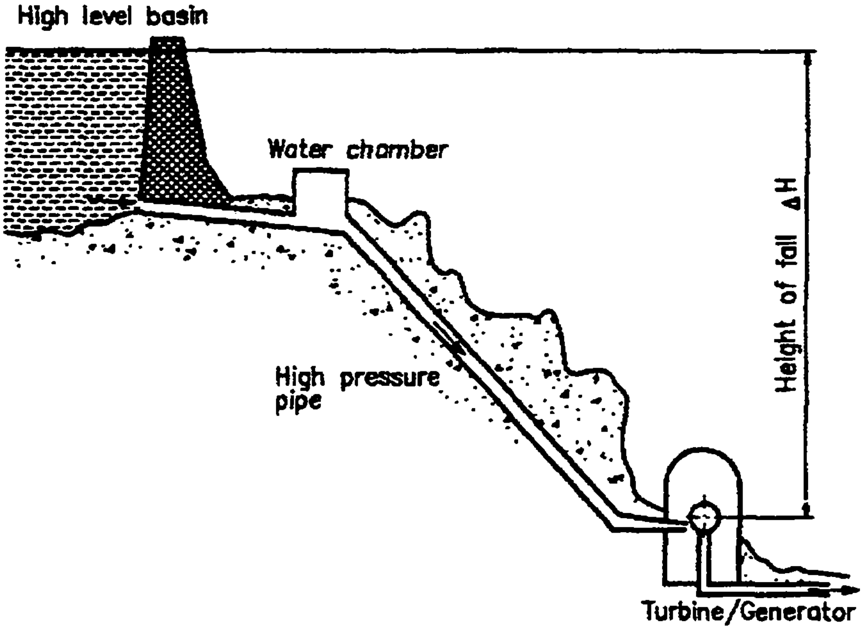
2.1 Hydraulic Power Station

Figure 2.1.1 River power plant



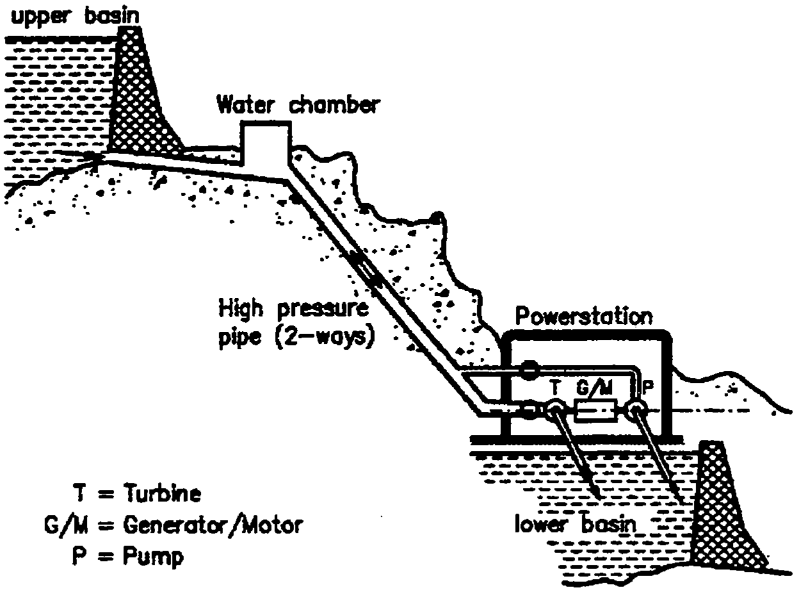
- Low water level difference (<25m)
- Low water pressure
- Large water quantity
- normally continuously operated
- for base load power supply

Figure 2.1.2 High level basin power plant



- Large water level difference
- High water pressure
- Low water quantity
- Simple ON/OFF operation
- for peak power demand

Figure 2.1.3 Pump storage power plant



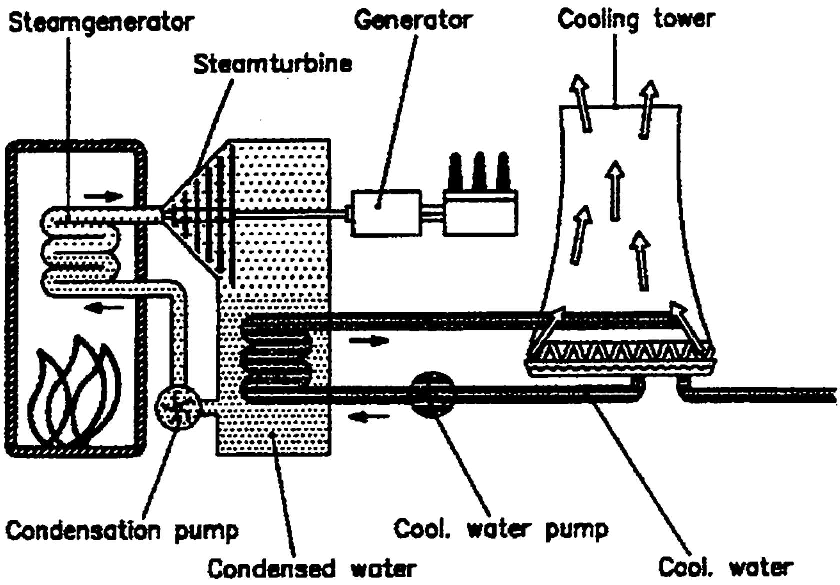
- Large water level difference
- High water pressure
- Minimum water quantity
- Simple ON/OFF operation
- for peak power demand
- re-use of water

Function:

High power demand phase: (day-time)	Lower power demand phase: (night time)
◆ High water pressure drives turbine-generator set ◆ Water collected in lower basin	◆ external power drives motor to pump water from lower to upper basin.

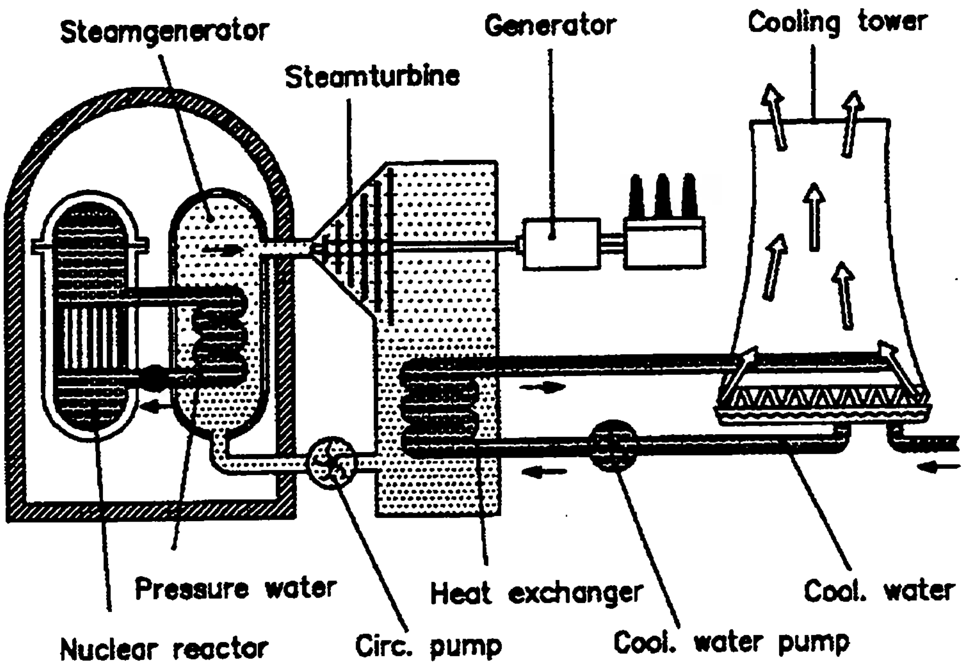
2.2 Thermal Power Plants

Figure 2.2.1 Fuel boiler systems



- Oil, gas or coal fired boiler
- High pressure steam drives steam turbine/generator (steam 200 bar/500°C)
- Efficiency <40%
- For base load demand
- Capacities: up to 800 MW p.u.

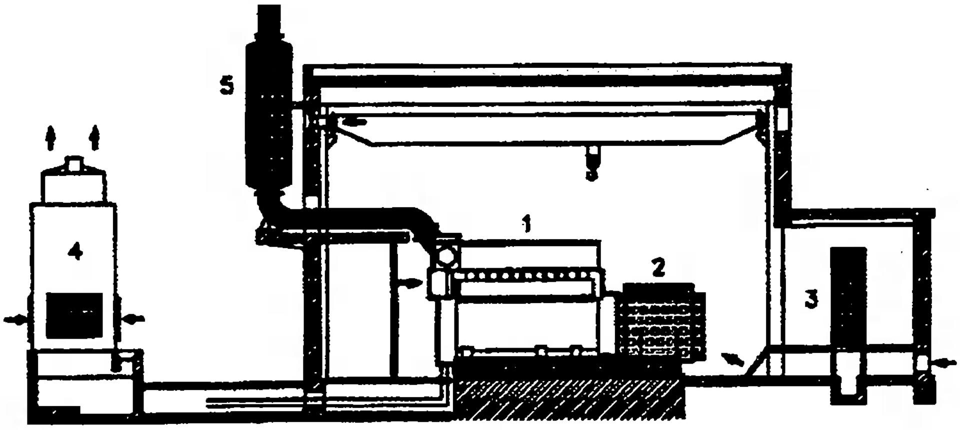
Figure 2.2.2 Nuclear power systems



- Boiling water reactor type
  - prim. circuit: 70 bar, 280°C
- Pressure water reactor type
  - prim. circuit: ~160 bar, 300°C
  - sec. circuit: ~60 bar, 270°C
- For base load demand
- Efficiency: < 35%
- Capacities: up to 1300 MW p.u.

2.3 Industrial Type Power Plants

Figure 2.3.1 Diesel power units



- Individual unit sizes for 0.5 - 40 MW
- Indoor and outdoor units
- Fuel: heavy fuel oil
  light fuel oil
- Efficiency: < 40%
- With heat recovery system to heat up e.g. heavy fuel oil

1 = Diesel engine

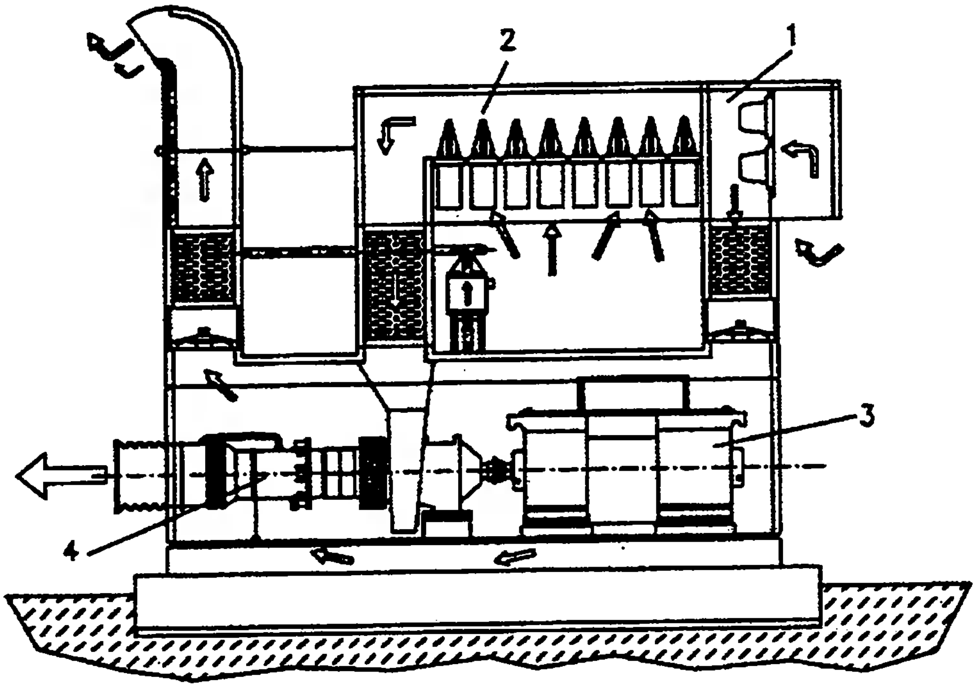
2 = Generator

3 = Control system

4 = Cooling tower

5 = Exhaust silencer

Figure 2.3.2 Gas turbine units



- Individual unit sizes of package units: 5 to 30 MW
- Combined cycle power plants up to 200 MW
- Complete packages for indoor and outdoor
- Fuel:
    - Natural gas
    - Diesel Oil
    - Heavy fuel oil
- Efficiency: < 30% (~ 50% for combined cycle P.P.)

1 = Air intake

2 = Air filter

3 = Generator

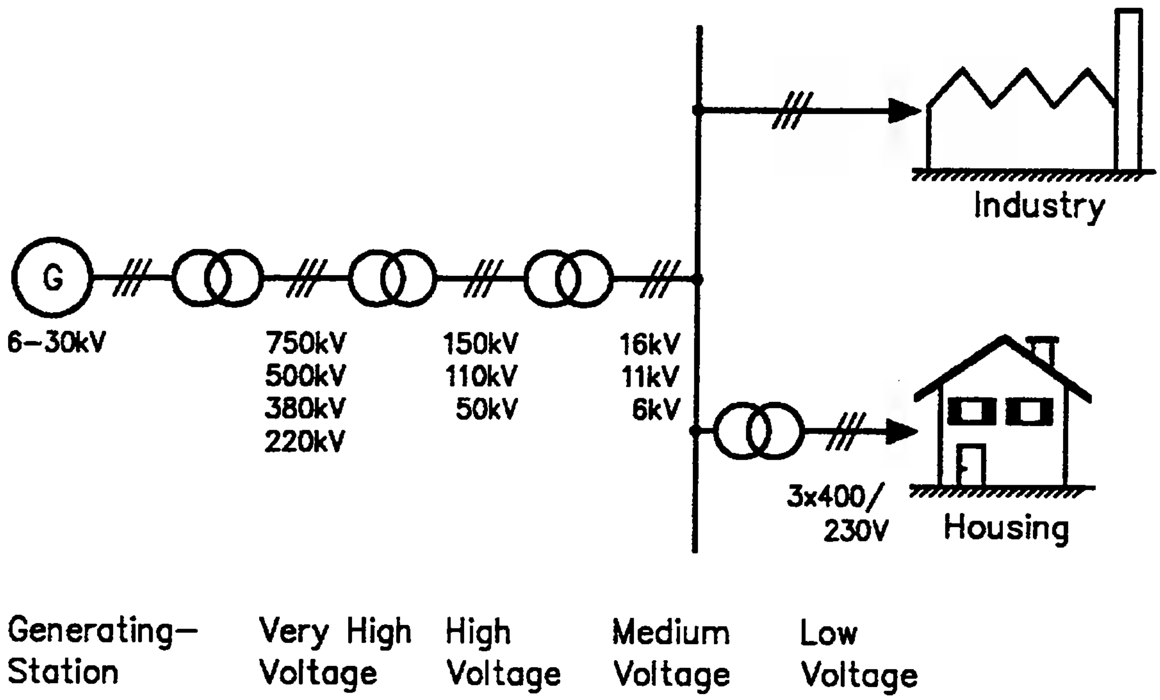
4 = Gas turbine

5 = Exhaust silencer

3. GENERAL DISTRIBUTION ARRANGEMENT

Electrical power generated in power plants need to be transported to the consumers. In order to avoid transmission losses, the AC-voltage is transformed at the generation station to extra high voltage levels (up to 750 KV~). At the consumer side, transformation to lower levels is required in order to feed the common industrial and household networks.

Figure 3.1 Typical transmission scheme



4. POWER TRANSMISSION

An extra high voltage (or maximum voltage) level network can for economical as well as for technical reasons only be operated by means of an overhead system. For short distances cables can be used for voltage up to approx. 400 kV.

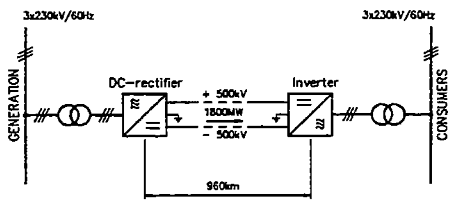
High voltage and medium voltage networks use both cables and overhead systems. In built-up areas cable connections are preferred whereas on open areas overhead lines are used mostly due to economical reasons.

4.1 Voltage levels:

- $>$ 150 kV = extra high (or maximum) voltage
- $>$ 50 kV = high voltage
- 1-50 kV = medium voltage
- $\leq$ 1 kV = low voltage
- $<$ 50 V = extra low voltage

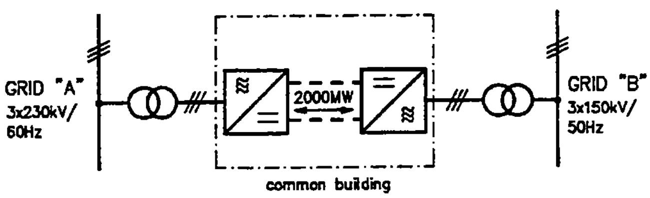
Loading of transmission lines in industrialised networks have in many cases reached their limits. Because of the high cost for construction of new transmission lines and delays due to environmental considerations, power supply companies planning to increase power transfer or to construct new extremely long transmission networks must today resort to new means. This includes so-called 'High Voltage Direct Current' links (HVDC-links). The 3-phase AC-supply is converted into a DC-voltage by means of static converter systems and at the other end of the transmission line re-converted by means of thyristor current converter into the 3-phase supply. HVDC-links reach voltage levels of up to ± 500 kV DC and transmit e.g. 3000 MW.

Figure 4.1.1 Concept of HVDC-link Nelson-River, Canada



HVDC-links are furthermore used for the coupling of two different networks systems, i.e. systems with different voltage levels and different frequencies (see Fig. 4.1.2). They are called 'short coupling'. In addition, these systems allow the interconnection of a stable with an unstable or weak network. A typical application is the connection of networks between the former eastern countries with western Europe.

Figure 4.1.2 Coupling of two different AC-systems by means of 'short HVDC-link'

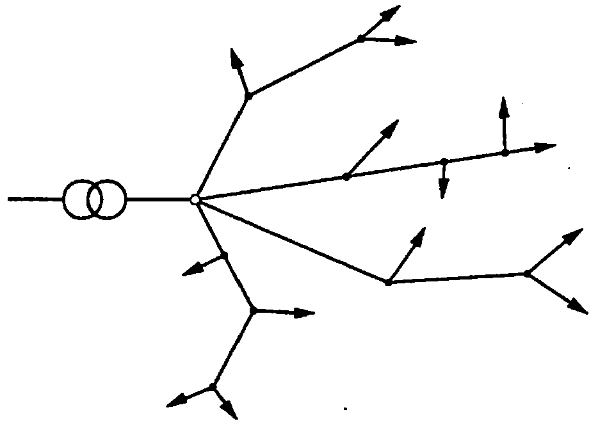


5. NETWORK SYSTEMS

5.1 Branch Power Supply

Branch networks are fed from one feeding point, a. generating plant or a main distribution station

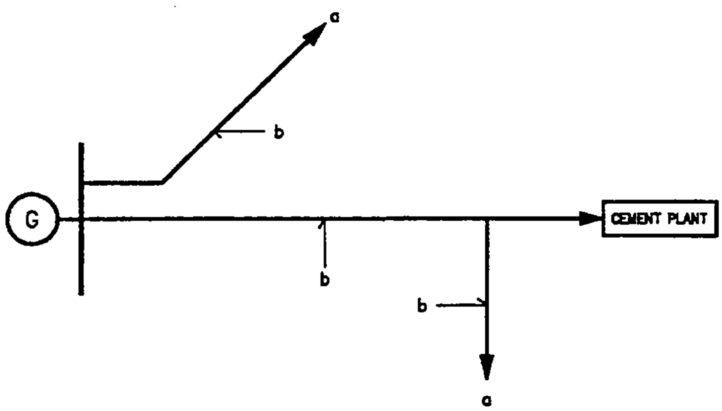
Figure 5.1.1 Branch power supply network



As can be seen from Fig. 5.1.2 below the power supply of the cement plant depends on one long branch line which has to be shared with another consumer. Any fault on the line caused by lightning, a falling tree, a. big bird, etc. will cause a black-out of the cement plant. Even a fault in the other consumers' network may trip the main circuit breaker and also disconnect the cement plant.

This unfortunate situation can be improved by trying to get a second supply line, preferably from a different source.

Figure 5.1.2 Branch power supply



G: power generating plant

a : power consumer

b: overhead power line

A branch power supply is not considered as a reliable source and ought to be backed up by installation of a generating station. The size of this (these) generator(s) will depend on the reliability of the power supply. A small emergency power generator (approx. 500 kW) has to be installed in any case to bring the plant under all circumstances to a safe standstill.

5.2 Ring Power Supply

The power distribution network (Fig. 5.2.1) is called a ring. It guarantees a very high reliability and uninterrupted power to all connected consumers also in case of a failure in one of the supplying overhead lines.

Under normal operation ring networks are normally 'open' in the middle of the ring, i.e. the two sections of the ring are operated as a branch power supply. In case of a disturbance, the ring is 'closed' and the supply to all consumers is available.

Figure 5.2.1 Ring power supply
a) normal operation ('open')
b) disturbance, disconnector 'closed')

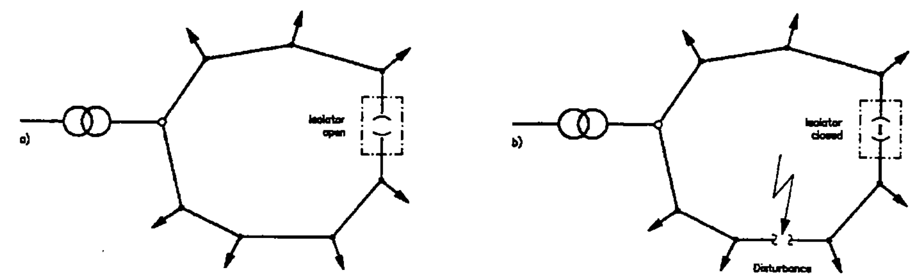
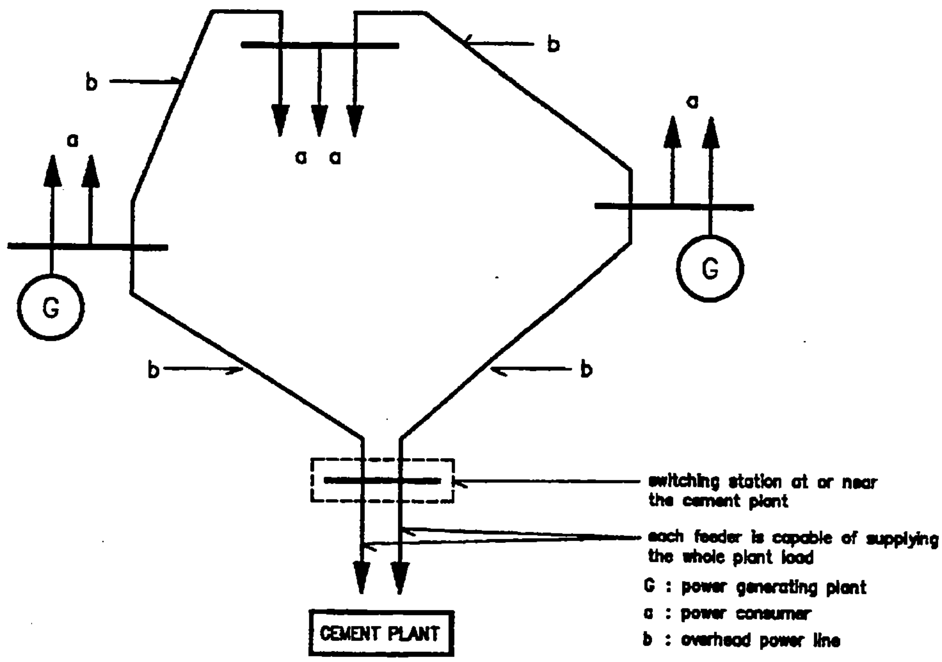


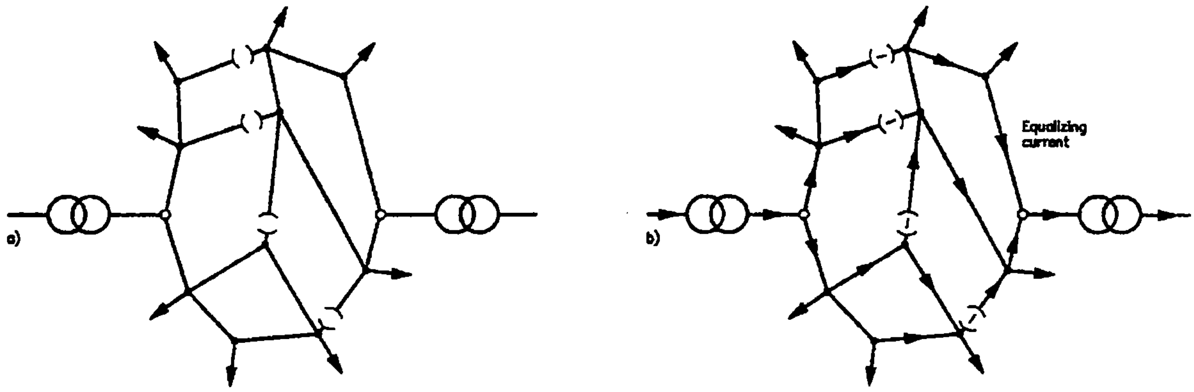
Figure 5.2.2 Preferred ring power supply system for cement plants



5.3 Mesh Networks

Interconnections within existing networks result in a so-called mesh network, which are normally fed from different sources i.e. generating stations. Availability of power as well as level of supply voltage are normally excellent, losses within the network are low.

Figure 5.3 Mesh network
a) 'open' operation (for LV-networks)
b) equalising current in network with different voltage levels



This type of networks requires high number of switching devices and protection equipment. Short circuit capacity is normally relatively high resulting in costly equipment. Mesh networks are applied for high voltage distributions as well as for low voltage distribution systems.

6. ENERGY CONSUMPTION / TARIFF STRUCTURE

6.1 General

Electrical energy can practically not be stored, this in contrary to other forms of energy carriers such as gas, oil, coal, wood, water etc. Therefore, production of electrical energy and consumption is always balanced and the supply companies undertake every effort to cope with the continuously charging demand. A certain surplus of generating capacity must be available to avoid energy supply bottle-necks.

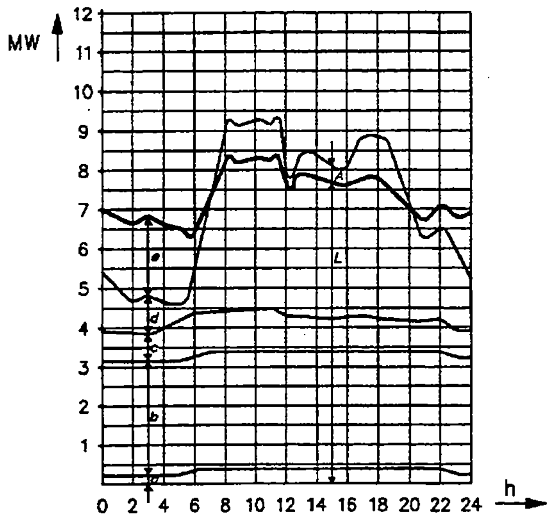
The application of different types of generating systems, the interconnection of large supply networks (Europe Interconnected grid from North of Norway to South of Italy) guarantee for a stable and continuous supply.

Small grid systems have the disadvantage to be weak, with unstable frequencies, heavy loads may lead to partial disconnection which may end in total black-outs for certain regions (Example: New York).

6.2 Typical Load Diagram

The graph Fig. 6.2 shows a typical demand over a period of 24 h and indicates the portions supplied by the various types of power stations (Example: Switzerland).

Figure 6.2 Load Diagram



Shares:

a =	convent. thermal power station	serving the base load
b =	Nuclear power stations	
c =	River power plants	
d =	High level basin power plants = peak load	
e =	imported energy	
L =	total power required	
A =	surplus produced, available for export	

The graph illustrates import phases during night-times (cheaper than own generation, partially used to 'refill' the high level basins) and export of peak-energy during day-time (expensive energy).

6.3 Tariff Structures

It is of utmost importance for the utility companies to be able to calculate the predictable consumption requirements. This in order to provide a stable supply and to eliminate sudden high demands which may affect and weaken the supply systems. For this reason supply contracts contain increasingly more certain power consumption limitation, so called load shedding requirements. These limitations are also reflected in different tariff levels as well as in penalties. For obvious reasons electrical energy consumed during night-time is considerably cheaper and supply companies encourage consumers to use 'night-energy'.

Energy contracts need to be negotiated with supply companies, a careful study considering the needs of the consumer and its equipment is the basis for an economical contract.

Tariffs normally distinguish between base charges calculated on the basic power demand (kW) and energy costs based on the actual consumption (kWh). Energy costs are normally connected to the time of consumption, in certain areas costs vary from hour to hour.

Extra charges (penalties) may have to be paid if agreed on limits on power demand are exceeded.

6.3.1 Typical Tariff example

The following shows a typical tariff structure showing cost-split for energy, power and reactive energy:

Active energy consumption charge

	Winter	Summer
High tariff	0-25 Mio. kWh: 6,3 cts/kWh > 25 Mio. kWh: 6,1 cts/kWh	0-20 Mio. kWh: 4,5 cts/kWh >20 Mio. kWh: 4,3 cts/kWh
Low tariff	0-20 Mio. kWh: 4,6 cts/kWh > 20 Mio. kWh: 4,4 cts/kWh	0-10 Mio. kWh: 2,6 cts/kWh > 10 Mio. kWh: 2,4 cts/kWh

Power demand charge

$ 29.--/kW, calculated on maximum demand of a quarter of a year.

The maximum demand of a quarter is the mean value of the four highest week-maxima, of a full-time period of 60 minutes.

Reactive energy consumption charge

The total consumed reactive energy during high tariff phases is limited to 45,5% of the active energy consumed (corresponds to average power factor (cos phi = 0,91).

Additionally consumed reactive energy will be billed to 2.1 cts/kVarh.

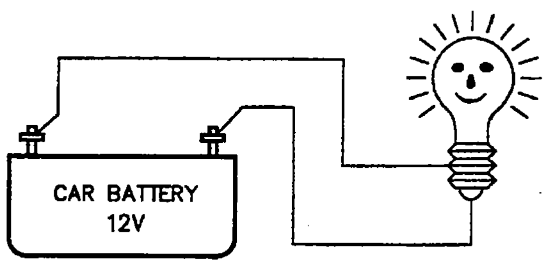
Tariff phases

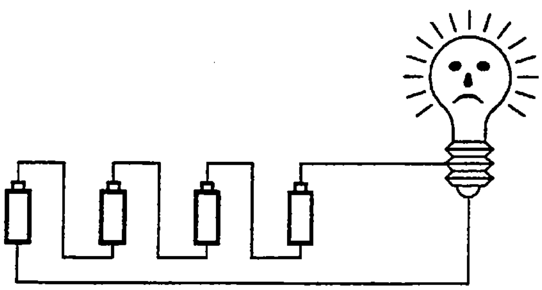
High tariff:	Monday-Friday Saturday	07.00 - 21.00 h 07.00 - 13.00h
Low tariff:	remaining time	
Summer:	April - September	
Winter:	October - March	

7. CAPACITIES OF POWER SUPPLIES

7.1 Weak and Strong Power Supplies

Figure 7.1 Weak and Strong Power Supplies





The supply voltage does not say anything about the strength of the supply. It is the available capacity of the network that determines the strength, or as it is called, the stiffness of a power supply.

The relation between the capacity of the source and the installed power at the consumer's plant is a measure for the stiffness of the electric power system.

The short circuit capacity - a theoretical figure expressed in MVA (Mega-Volt-Ampère) - is based on the assumption of a 3-phase short circuit between the source and the consumer. It is the product of the short circuit current and the line-to-line voltage.

$$S_K = I_{K3p} \times U_N \times \sqrt{3} \text{ (MVA)}$$

S_K : short circuit capacity of a 3-phase system

I_{K3p} : short circuit current of a 3-phase system

U_N : normal voltage

$\sqrt{3}$: factor for a 3-phase system

A strong power supply of approx. 300 MVA is normally required to operate a cement plant.

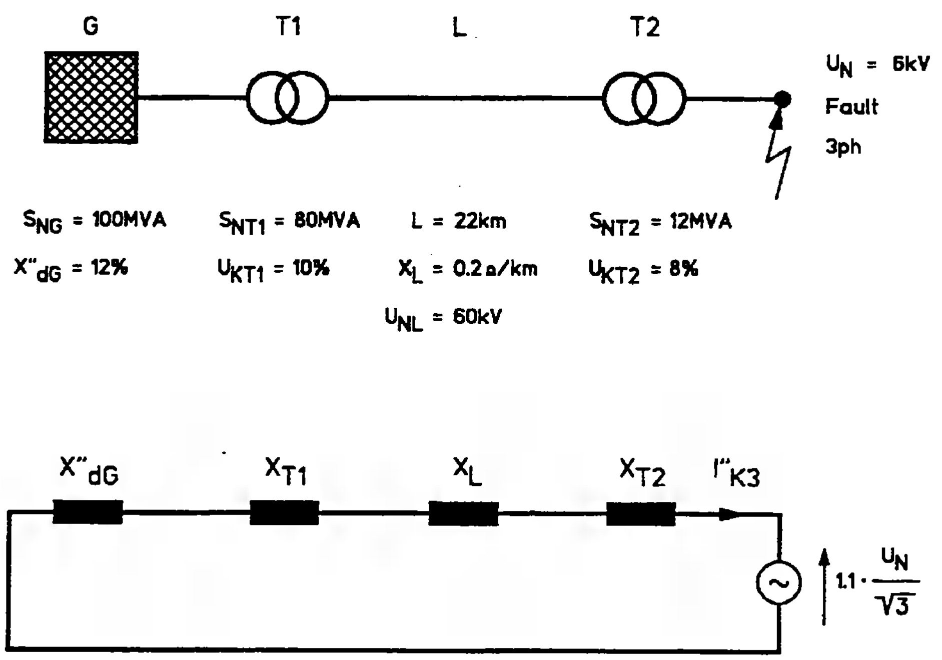
7.2 Calculation of Short Circuit Capacity

Calculation of symmetrical short circuit capacity S_{K3}' (MVA) resp. short circuit currents I_{K3}" (kA).

Network components:

S_N	=	rated apparent power	(MV)
U_N	=	rated system voltage	(kV)
E"	=	initial voltage of power supply	(kV)
c	=	factor E" / $U_N \approx$ 1.1	
$X"_d$	=	subtransient reactance	(%)
U_K	=	impedance voltage drop	(%)
X_L	=	impedance per conductor	(Ω/km)
$I"_K$	=	initial symmetrical short circuit current	(kA)
$S"_K$	=	initial symmetrical short circuit capacity	(MVA)

Figure 7.2 Network components



Calculation method: The so called '% / MVA system' is particularly useful for calculating short circuit currents in high voltage networks.

There is no need to reduce the impedance of different voltage levels to the voltage of the faulty part of the network.

This method is especially used for rough estimations in the project phase.

$$X''_{G} = X''_{dG} \times \frac{100}{S_{NG}} = 0.12 \times \frac{100}{100} = 0.12\%/MVA$$

$$X_{T1} = U_{KT1} \times \frac{100}{S_{NT1}} = 0.10 \times \frac{100}{80} = 0.13\%/MVA$$

$$X_{L} = X_{L} \times L \times \frac{100}{U^2_{NL}} = 0.20 \times 22 \times \frac{100}{60^2} = 0.12\%/MVA$$

$$X_{T2} = U_{KT2} \times \frac{100}{S_{NT2}} = 0.08 \times \frac{100}{12} = \underline{0.76\%/MVA}$$

$$\sum X = \underline{\mathbf{1.04\%/MVA}}$$

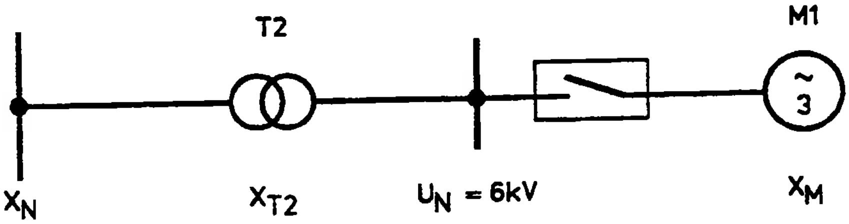
$$S''_{K3} = C \times \frac{100}{S_{NT2}} = 1.1 \times \frac{100}{1.04} = \underline{\underline{\mathbf{106 \quad MVA}}}\text{(at 6kV)}$$

$$I''_{K3} = \frac{S''_{K3}}{\sqrt{3} \times U_{N}} = \frac{106}{\sqrt{3} \times 6} = \underline{\underline{\mathbf{10.2 \quad kA}}}\text{(at 6kV)}$$

7.3 Calculation of Voltage Drop

Calculation of network voltage drop due to starting of a large motor.

Figure 7.3 Calculation of network voltage



a) Squirrel cage motor (direct starting) $I_S = 5 \times I_N$

$$X_N = C \times \frac{100}{S''_{K3}} = 1.1 \times \frac{100}{300} = 0.37\%/MVA$$

$$X_{T2} = U_{KT2} \times \frac{100}{S_{NT2}} = 0.08 \times \frac{100}{12} = 0.67\%/MVA$$

$$X_{M1} = \frac{100}{S_{NM1} \times I_S} = \frac{100}{3.5 \times 5} = \underline{5.70\%/MVA}$$

$$\sum X = \qquad = \underline{\mathbf{6.74\%/MVA}}$$

$$U_{N6kV} = \frac{(X_N + X_{T2}) \times 100}{\sum X} = \frac{1.04 \times 100}{6.74} = \underline{\underline{\mathbf{15.4\%}}}$$

b) Slipring motor (rotor starter) $I_S = 1.2 \times I_N$

$$X_N = 0.37\%/MVA$$

$$X_{T2} = 0.67\%/MVA$$

$$XM1 = \frac{100}{3.5 \times 1.2} \qquad 3.5 \times 5 \qquad = \underline{23.80/MVA}$$

$$\sum X = \qquad = \underline{24.84\%/MVA}$$

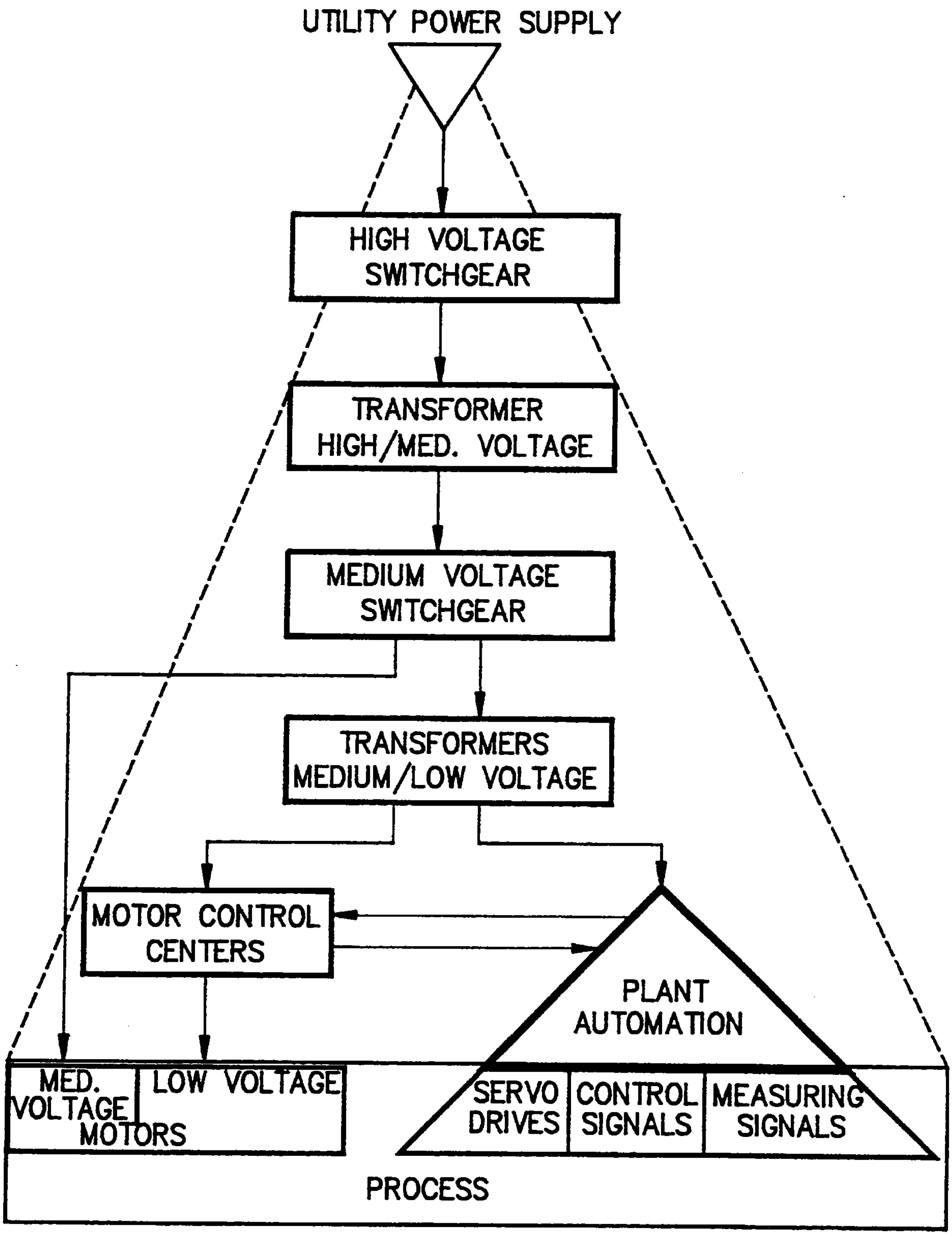
$$U_{N6kV} = \frac{(XN + X_{T2}) \times 100}{\sum X} = \frac{1.04 \times 100}{24.84} = \underline{\underline{\mathbf{4.2\%}}}$$

The normal output of a motor is guarantied within a voltage range of $U_N \pm 5\%$

In most cases a voltage drop at the motor terminal during the starting phase of 10% is acceptable and will not cause disturbances to other equipment.

For more important voltage drops closer investigations are required.

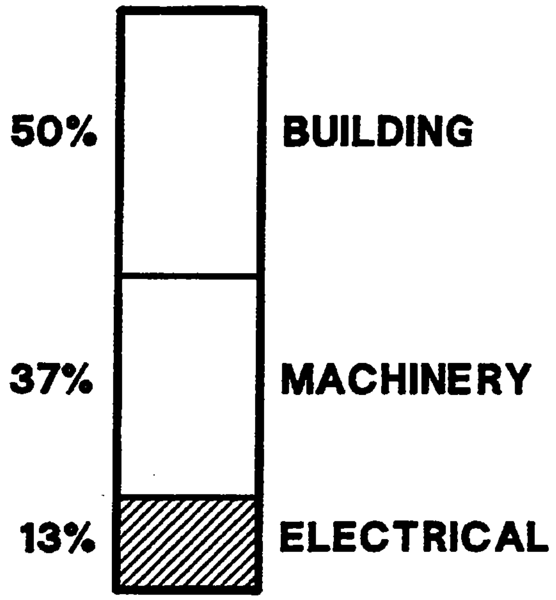
8. STRUCTURE OF ELECTRICAL SYSTEMS IN A CEMENT PLANT



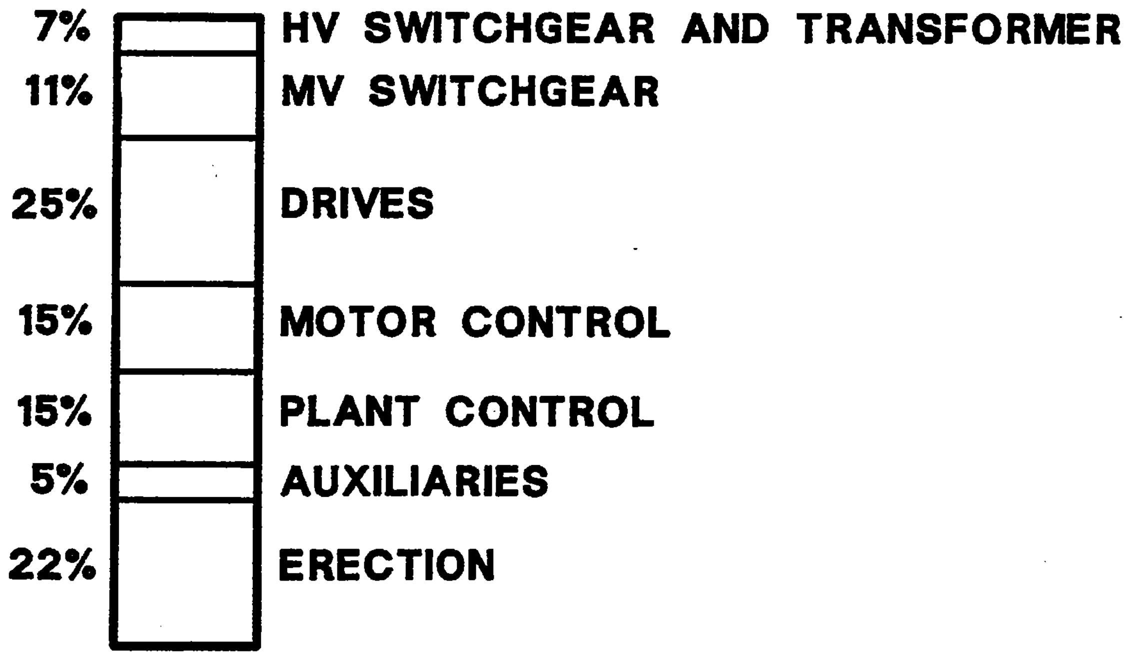
POWER SUPPLY AND POWER DISTRIBUTION
ELECTRIC MOTORS
AUTOMATION SYSTEMS

9. INVESTMENT COST OF A CEMENT PLANT

TOTAL COST

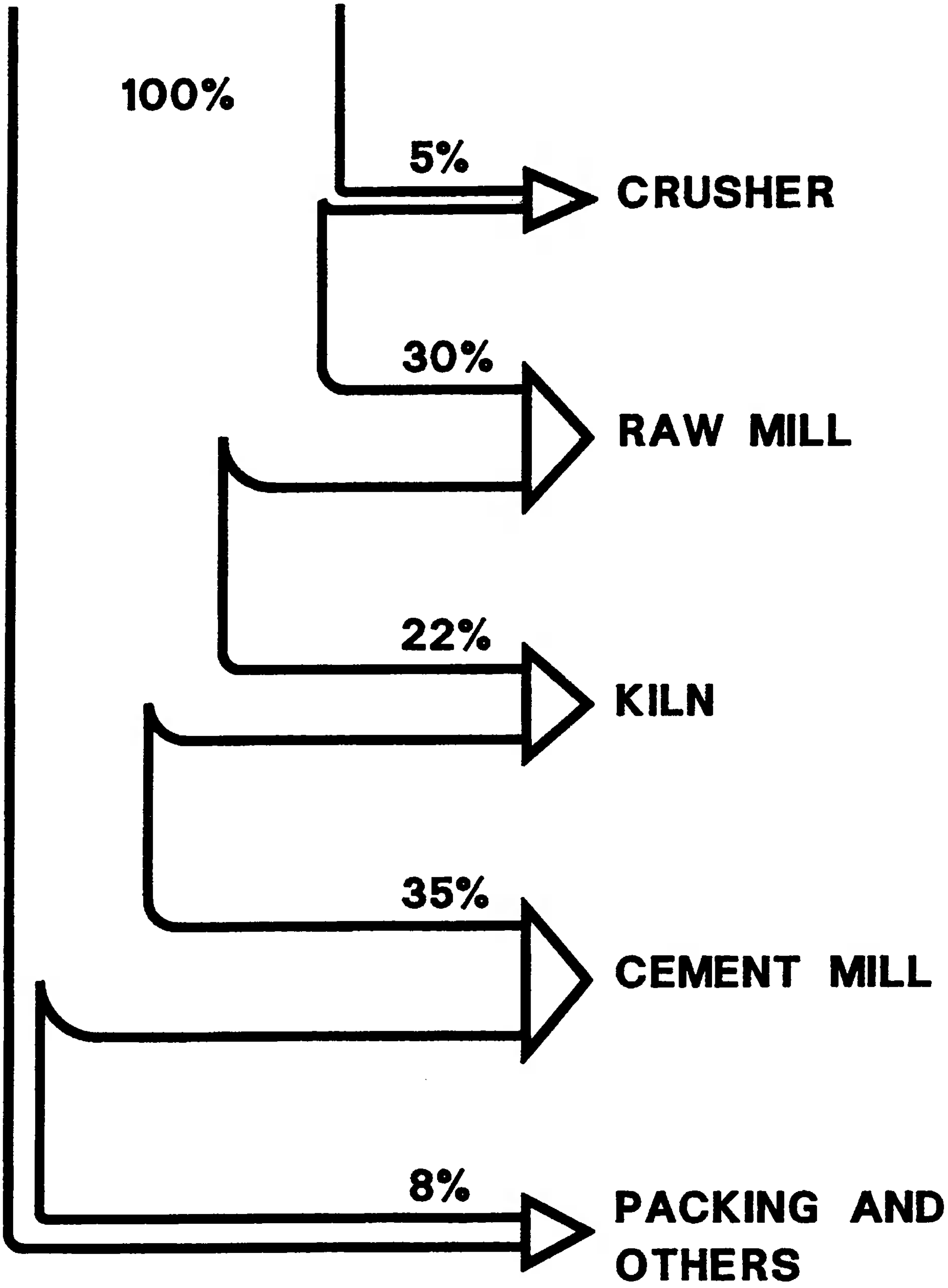


COST OF ELECTRICAL EQUIPMENT



NOTE: THE PERCENTAGE VALUES MAY VARY FROM PLANT TO PLANT

10. POWER CONSUMPTION OF A CEMENT PLANT



- 100 kWh/t.
- Peak x 2 a 3